COOPERATIVE NATIONAL PARK RESOURCES STUDIES UNIT
UNIVERSITY OF HAWAII AT MANOA
Department of Botany
Honolulu, Hawaii 96822
(808) 948-8218

Clifford W. Smith, Unit Director
Associate Professor of Botany

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Joan H. Fellers and Gary M. Fellers
and
James D. Jacobi

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VEGETATION CHANGES IN A SUBALPINE GRASSLAND IN HAWAI'I FOLLOWING DISTURBANCE BY FERAL PIGS

James D. Jacobi
Department of Botany
University of Hawaii at Manoa
Honolulu, Hawaii 96822

ABSTRACT

Changes in the vegetation following disturbance by feral pigs in a subalpine grassland in Haleakala National Park were studied to determine if the native plants could maintain dominance over introduced species. Results of vegetation sampling along transects established through a 120 ha study area showed that native species dominated the grassland; however, 23.2% of the ground cover had been uprooted by pigs. After the vegetation inside a small fenced exclosure was monitored for five years, it was found that native and introduced species competed equally for areas uprooted by pigs. It was concluded that if feral pigs continue to forage in the grassland, introduced plant species will continue to increase in both cover and abundance.

RECOMMENDATIONS

1. Eliminate pigs from the Kalapawili grassland. The results of this study have shown that continued rooting of the area by feral pigs will lead to an increase in the cover and abundance of introduced plant species in the grassland. If the pigs are eliminated, the native species will at least maintain their present dominance of the vegetation.

A pig-proof fence should be constructed at the lower edge of the grassland where it merges into the native scrub vegetation, starting from the edge of Kipahulu Valley and running around the grassland, up to the area of Lau'ulu peak.

A preferable solution would be to construct, where feasible, a pig-proof fence along the vicinity of the National Park boundary, on the outer north slope from Kipahulu Valley to Ko'olau Gap, deviating from the actual boundary line only where the terrain will not allow for a secure fence. This fence would additionally serve as a barrier to pig movements in the native scrubland on this slope.

2. Eliminate the blackberry plants which have become established in the lower portions of the grassland and scrub. Blackberry (Rubus penetrans) has the potential for increasing in both distribution and abundance from the plants presently established in this area. It could form impenetrable thickets within a few years. The sooner these plants are removed the better. This control program should be coordinated with the Hawaii State Department of Land and Natural Resources to additionally remove the blackberry plants established in the upper portions of the native forest in the Ko'olau Forest Reserve.

3. Continue monitoring the vegetation inside the Kalapawili exclosure, and determine long-term changes in the grassland community following removal of the pigs.

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INTRODUCTION

The native Hawaiian biota, having developed under extraordinary evolutionary conditions, is unique to the world (Zimmerman 1948; Carlquist 1970). As these volcanic islands have always been extremely isolated from continental ecosystems by the vast expanse of the Pacific Ocean, only a very limited number of plants and animals, capable of being dispersed over long distances, became successfully established in Hawai'i. Fosberg (1948) estimated that as few as 272 original colonizing plant taxa have given rise to nearly 3000 taxa of Hawaiian flowering plants, 99% of which are endemic (St. John 1973). Similar rates of endemicity have been determined for other Hawaiian biological groups, including insects (Zimmerman 1970) and forest birds (Berger 1972). Notable groups of organisms which have never been part of this native biota include land mammals, reptiles, amphibians, and plants such as figs, bamboos, and conifers.

With the arrival of man into Hawai'i, first from Polynesia, between 1500 and 2000 years ago, and more recently from Europe and America starting in 1778, a great number of additional plants and animals have been either purposely or accidentally introduced into the Islands. The establishment and interaction of these introduced species have drastically altered the ecosystems they have invaded, with subsequent reduction in numbers, displacement of, or, in many cases, elimination of the native species.

Introduced herbivores such as pigs (Sus scrofa L.), goats (Capra hircus L.), sheep (Ovis aries L.), cattle (Bos taurus L.), horses (Equus caballus L.), and deer (Axis axis (Erxleben)) have been, and still are, primary factors in the degradation of the native habitats. Of these large ungulates, pigs have been in Hawai'i the longest, having first been introduced by the early Polynesian settlers (Tomich 1969). However, the Hawaiian pig or pua'a is presumed to have been relatively small in size, and for the most part remained around villages in the lowlands under semi-domestication. The pigs brought by Captain James Cook in 1778, and subsequently by later visitors to Hawai'i, were much larger animals which eventually interbred with and replaced the Polynesian stock and spread into the upper elevation habitats (Tomich 1969; Warshauer 1980). All of the other large mammals were introduced into the Hawaiian Islands since 1778, and each new species soon resulted in added destruction to the native biota.

In recent years, emphasis has been placed on studying the effects which these introduced animals have on the native Hawaiian biota, with the intention of developing management strategies for threatened communities and their species elements. This paper reports the results of one such study conducted from 1973 through 1978 to determine to what extent disturbance by feral pigs, and subsequent invasion by introduced plant species, were having on the long-term stability of a native subalpine grassland on the island of Maui, Hawai'i.

DESCRIPTION OF THE STUDY AREA

Field work was conducted in the Kalapawili grassland, located on the outer northeast slope of Haleakalā volcano (Fig. 1). The Kalapawili grassland is the most extensive upland native grassland found in Hawai'i, encompassing an area of approximately 120 ha (300 acres) between the elevations of 2255 and 2440 m (7400 & 8000 ft). Its eastern and southern boundaries are sharply delineated by Kipahulu Valley and the Haleakalā summit depression, respectively. To the north and west, however, the grassland diffuses into a subalpine scrub habitat. Below 2135 m (7000 ft), the scrub community gives way to a dense native rain forest which then continues downslope to at least 490 m (1600 ft) elevation (Fig. 2). The Kalapawili grassland is a regular foraging area for the endemic Hawaiian short-eared owl or pueo (Asio flammeus sandwichensis), Hawaiian goose or nēnē (Branta sandvicensis), and the Golden Plover or Kōlea (Pluvialis dominica) (Berger 1972).

Native Plant Species

Twenty-one species of vascular plants were found in the grassland proper, 15 of which were native and only six introduced species (Appendix A). The most dominant plant species by far was the endemic bunchgrass Deschampsia australis which formed a very dense ground cover in all areas except where heavily uprooted by pigs. Most of the other native species were found to be generally widely distributed, but in low abundance and cover: these included the native rush, Luzula hawaiiensis, bracken fern (Pteridium aquilinum), and a small species of 'ōhelo (Vaccinium berberifolium). The larger native shrubs--i.e., 'ākala (Rubus hawaiiensis), 'ama'umau (Sadleria cyatheoides), pūkiawe (Styphelia tameiameiae), and 'ōhelo (Vaccinium reticulaturn)--were found growing in better drained sites, both in the gulches which run through the grassland and on rock outcrops with-shallow soil (Forehand 1970).

Henrickson (1972) reported that the large Maui greensword (Argyroxiphium virescens Hbd.) was once common along the upper portions of Kalapawili Ridge. This species is no longer found in the area and Henrickson speculated that it was eliminated by feral pigs, goats, and/or cattle during the past 100 years. One small group of Maui silverswords or 'āhinahina (A. sandwicense) was recently found growing in the upper portion of the grassland near the peak Pōhaku-palaha; however, this population has since been destroyed by goats. Another small patch of silverswords still persists at a lower elevation on this slope growing on relatively inaccessible cliffs at Pu'u'alaea.

Introduced Plant Species

Three of the six introduced plant species established in the Kalapawili grassland--velvetgrass (Holcus lanatus) and two herbaceous species: gosmore (Hypochaeris radicata) and sheep sorrel (Rumex acetosella)--were found to be both widespread and fairly common. Gosmore and sheep sorrel were generally found growing in open situations, particularly where the grass cover was disturbed and removed by pigs. Velvetgrass was found growing in small, dense patches but also was found invading pig-rooted areas.

The other three introduced species were found to have more restricted distributions: the common toad rush (Juncus bufonius) and Glenwoodgrass (Sacciolepis indica) were found only adjacent to a horse trail running through the upper portion of the grassland, and prickly Florida blackberry (Rubus penetrans) only in the lower portions of the study area both near [illegible]alaea and above Lake Wai'ānapanapa (Fig. 2). Blackberry more than doubled its distributional area in the grassland between 1973 and 1980. This species is extremely aggressive and steps should be taken immediately to control its spread.

FERAL ANIMALS

Both feral pigs and goats were frequently found in the Kalapawili grassland during this project. Formerly cattle were also grazed in this area; however, this practice was discontinued in 1935 (Forehand 1970). Although the goats continue to have a serious impact on the native woody vegetation around the grassland and elsewhere on Haleakalā (Yocom 1967), their present impact on the native species remaining in the grassland was considered to be minimal.

The greatest damage within this community was found to be caused by the pigs, primarily because they uprooted extensive areas of the vegetation while feeding. The pigs were not resident in the grassland but came up in the late afternoons and evenings from the forest and scrub communities below to feed. Generally they were seen feeding singly or in small family groups, moving slowly through the area in search of suitable forage. Their two preferred foods here were gosmore leaves and roots, and rhizomes of the bracken fern.

OBJECTIVES OF THIS STUDY

Three major objectives were addressed in this project:

1. To describe quantitatively the species composition of the Kalapawili grassland as a whole, and to determine the amount of area uprooted by pigs;

2. To determine the role pigs play in the introduction and establishment of introduced plant species in this grassland: and

3. To determine to what extent the native vegetation may be expected to recover if feral pigs were entirely removed from this area.

METHODS

Establishment of Three Transects Through the Grassland

The first phase of this project was to determine the distribution and abundance of the plant species, and to quantitatively assess the degree of pig rooting throughout the grassland. For this purpose, three transects, each approximately 1000 m long, were laid out through the area in July 1973 (Fig. 2). Two-by-two meter plots were sampled at 20 m intervals along each transect line. In each plot, the cover for each plant species present was estimated, and the percent of the ground area which had been recognizably uprooted by pigs was recorded.

Pig rooting was distinguished into three categories corresponding to the relative age of disturbance. "Fresh rooting" was defined as ground which had obviously been very recently uprooted, the overturned vegetation still green; "recent rooting" showed the ground still noticeably disturbed but the plant material all dead; and "old rooting," in which most of the upturned litter had disappeared from the ground surface, with some invasion of seedlings noted.

Monitoring Vegetation Changes Inside a Fenced Animal Exclosure

In March 1974, a 10 x 40 m fenced animal exclosure was constructed in a central portion of the Kalapawili Ridge grassland (Fig. 2). By periodically sampling the vegetation inside the exclosure, changes in the plant species composition and abundance were monitored in a situation free from repeated pig disturbance. Additionally, comparisons could be made by viewing vegetational changes in the area immediately outside the exclosure, which could still be disturbed by pigs.

Ten 20 m-long transects, each with 10 m inside the fenced area, were laid out through the exclosure, and two 5 m segments outside the fence (Fig. 3). When the exclosure was constructed it was oriented so that Transects 1 to 5 covered an area which had recently been heavily uprooted by pigs, while Transects 6 to 10 were located in a less disturbed area. Sampling along each transect was conducted using the point-frequency technique (Mueller-Dombois & Ellenberg 1974), which employs an aluminum frame 1 m long, holding upright five pointed steel rods. As the frame is placed on a 1 m segment of the transect, each of the five rods is lowered to the ground; whatever is first touched by the tip of that rod is recorded for that sample point. By this means, the vegetation can be characterized in terms of percent cover, by the number of points intercepting each species. One hundred sample points were recorded for each transect, 50 points inside and 50 points outside the exclosure.

The vegetation inside and outside of the exclosure was sampled in both March and October for the years 1974 to 1976, and in March only for the years 1977 and 1978.

RESULTS

Assessment of Plant Cover and Pig Rooting in the Grassland

In summarizing the information gathered along the three long transects through the grassland (Table 1), of the plant species found there, only Deschampsia australis, velvetgrass, and gosmore were recorded with greater than 5% foliage cover. Deschampsia was by far the most dominant species with a mean cover value of 57.3%. The other native plant species were found to cover just 1.1%, giving a total of less than 60% cover for all the native species in the grassland. This value is compared with a total of 18.4% cover for the three exotic species: velvetgrass (9.5%), gosmore (8.0%), and sheep sorrel (0.9%), plus 23.2% of the ground covered with plant litter or barren ground resulting from pig rooting.

Vegetation Changes Inside and Outside the Fenced Exclosure

After analyzing the results of the vegetation sampling inside and outside the exclosure from 1974 to 1978, it was evident that changes in the vegetation outside the fence were very similar to the changes which took place inside the exclosure. Apparently, the presence of the fence was enough to keep pigs away from the vicinity, as with few exceptions, little new rooting was noted there each time the area was resampled. Therefore, most of the emphasis in this phase of the study was placed on analyzing changes in the vegetation inside the fence, with a known zero-level of pig disturbance since 1974.

TABLE 1. Summary of the amount of pig rooting and plant cover from the three long transects in the Kalapawili grassland (where * = native species).

	PERCENT COVER
PIG ROOTING	
Fresh	4.3
Recent	9.7
Old	9.2
PLANT SPECIES	
*_Deschampsis australis_	57.3
Holcus lanatus	9.5
Hypochaeris radicata	8.0
Rumex acetosella	0.9
*Other species	1.1

The change in plant cover for the portion of the exclosure that had initially been heavily uprooted (Transects 1 - 5), was considerably different from what was seen in the less disturbed portion (Transects 6 - 10) (Fig. 4). For Transects 1 to 5, Deschampsia showed a strong increase each year from 1974 to 1978. Cover for velvetgrass also increased; however, the change became markedly less after 1975. Gosmore showed an increase to 9.2% in 1975, then decreased steadily to 2.8% cover in 1978. Sheep sorrel, on the other hand, was at its highest cover value in 1974 (9.6%), then decreased steadily each year to 2.0% in 1978. No noticeable change was seen in the cover of the other plant species recorded, which were at low levels of cover from the start.

The initial increase, then decrease in the abundance of gosmore and the continued decrease in the cover of sheep sorrel, suggests that these two species were early seral species, following the initial disturbance of the ground cover, but were subsequently displaced by the two grass species.

In contrast, Transects 6 to 10 showed little change in individual plant species cover over the years sampled. Deschampsia increased slightly from 1974 to 1978 but had a slight decrease in 1975. Velvetgrass showed a slight increase in cover in both 1975 and 1976 but decreased again to its original level by 1978. Very little change was seen in the cover values for the remaining species.

Changes in Plant Cover for Each Transect

In the above discussion, treating the transects as two groups in portions of the exclosure which had been initially disturbed and relatively undisturbed, was useful for obtaining an overview of the changes in plant cover after removing the influence of pigs from the area. However, closer examination of the data showed that many of the transects started with different amounts of each species, and consequently changed in a slightly different manner than indicated by the two groups. Therefore, to more realistically follow the plant succession from these different starting points of species composition, changes between each transect were also compared for the years 1974, 1976, and 1978.

One way to compare changes in plant cover for all 10 transects over the three years analyzed is to examine graphs of percent cover for the different species. However, this method was found to be difficult owing to the fact that 10 transects sampled for three years gave a total of 450 paired comparisons which could be made.

As an alternative, Bray and Curtis ordination plots were used to display the relationships between all transects, for all three years, in a single figure. This multivariate technique of plot analysis is based on a similarity index between pairs of plots (in this case, transects for each year), determined by the quantitative values of species common to each pair. The similarity index used in this case was Bray and Curtis' modification of Sorensen's quantitative index, which is calculated by summing up the lesser cover values for each species shared by the pair of plots (in this case, 450 calculations). Each similarity index is then converted to a dissimilarity value (i.e., the relative difference between each pair of plots) by subtracting the similarity index from 100. A detailed explanation of this ordination technique is given by Mueller-Dombois and Ellenberg (1974).

A two-dimensional graph is then generated by geometrically plotting the relative positions of each sample plot from selected end-point plots, on both the x- and y-axes. In such a display, sample plots which are located close to each other on the graph are relatively similar in species composition, and those which are widely separated are less similar.

In this case, each year for each transect was initially treated as a separate vegetation sample, yielding 30 different plots (10 transects per year for three years). The x- and y-coordinates for each sample were then calculated as described above, and plotted on an ordination graph. Finally, each of the 30 ordination points was identified as to transect number and year (Fig. 5). If the ordination positions for the two transects are displayed for each year, a noticeable progression can be seen in the plots, starting with a widely-dispersed pattern for the 10 transects in 1974 (Fig. 6), a closer pattern in 1976 (Fig. 7), and an even closer pattern for the 10 transects in 1978 (Fig. 8). Moreover, the transects which showed the greatest change in ordination position were transects 1, 2, 3, and 4, between 1974 and 1976. Those four transects were the most heavily disturbed when the exclosure was built in 1974. The ordination position of transect 10, however, changed least of all over the years, indicating its vegetation composition was fairly stable over the four years sampled.

DISCUSSION

By following the changes in plant species composition and cover in the 10 x 40 m exclosure, a successional model has been developed to predict how the vegetation of the grassland as a whole may stabilize if the influence of pigs is removed. One basic question which was addressed in this project was whether or not the native species can maintain, or even increase, their dominance within the community, or whether the exotic species, principally velvetgrass, will increase in cover without the influence of pigs.

The 10 transects sampled in the fenced exclosure show the types of change which may be expected. Returning to the ordination plot, an attempt was made to identify groups of transects, regardless of year, which showed similar species composition (Fig. 9). Six groups of plots were identified, which are described in Table 2. Group A represents vegetation samples most dominated by native species (i.e., Deschampsia), while Group F includes those samples most heavily disturbed and with the least cover by native species.

When the plot groups for the 10 transects in 1974 are compared with the groups for these transects in 1976 and 1978, only one transect (Transect 10) remained within the same group for all three years analyzed. The greatest total change was seen in Transects 1 to 4, which were the most heavily disturbed in 1974.

Of the remaining transects, 1 and 3 remained in Group E for 1976 and 1978, and Transects 6 and 7 remained in Group B for these same two years. If the species composition of the transects can be considered to have stabilized by not reflecting a change in group for two sample perioids, then Group B and E may represent relatively stable successional end-points along with Group A. This being the case, Transect 5, which joined Group B in 1978, would not be expected to change significantly either in the near future; the remaining four transects--2, 4, 8, and 9--were all in Group D in 1978. In both instances when transects were included in Group D in the past (Transect 7 in 1974 and 5 in 1976), they have always changed to Group B in the next sampling period. Therefore, it might be expected that Transects 2, 4, 8, and 9 will also stabilize in Group B.

Plant Succession Scheme

The succession from heavy pig disturbance to a stable plant cover was found to be as follows. Initial colonization of disturbed ground is by the fast growing herbaceous species gosmore and sheep sorrel. After one year, the grasses Deschampsia and velvetgrass become reestablished in the area and begin to crowd out the herbs. From this point, the amounts of Deschampsia and velvetgrass both steadily increase, covering all of the barren ground. The plant cover stabilizes, dominated in all cases here by Deschampsia, but with two different levels of velvetgrass: greater than 20% for Group E, and 10% to 20% for Group B. These different amounts of established cover of velvetgrass probably reflect the amount of this species immediately adjacent to the disturbed area. In only one instance during the years in which the exclosure was monitored, did the amount of velvetgrass decrease more than 10% cover, with a corresponding increase in Deschampsia. Similarly, no case was seen in which Deschampsia decreased by more than 20%. In other words, it appears that the boundaries between Deschampsia and velvetgrass are relatively

TABLE 2. Description of the six plot groups recognized on the ordination diagram (Fig. 9).

PLOT GROUP	DESCRIPTION
A	Abundant *Deschampsia* (80% cover), little *Holcus* (5% cover)
B	Abundant *Deschampsia* (80% cover), much *Holcus* (10 - 20% cover)
C	Much *Deschampsia* (60 - 80% cover), little *Holcus* (5% cover)
D	Much *Deschampsia* (60 - 80% cover), much *Holcus* (10 - 20% cover)
E	Abundant *Holcus* (20% cover), much *Deschampsia* (60 - 80% cover)
F	Heavily disturbed, little *Deschampsia* (40%), little *Holcus* (5% cover)

fixed once they recolonize all of the ground which had been uprooted.

The other stable plant cover state is the situation in which Deschampsia is very abundant (greater than 80% cover), with very little velvetgrass present. This was seen only in the case of Transect 10, which did not move out of Group A over the years sampled. This suggests that if the Deschampsia cover is not disturbed, or only very slightly so, Deschampsia will maintain almost complete dominance of the vegetation.

CONCLUSION

Despite the fact that the Kalapawili Ridge grassland shows a high degree of disturbance by pig rooting (23.2%), the vegetation is still dominated by native species, primarily Deschampsia australis. However, based on the results of the exclosure study, each time the vegetation here is heavily disturbed by rooting, exotic plants--mainly velvetgrass--will become better established and eventually increase in total cover in the grassland. These results concur with the findings of Spatz and Mueller-Dombois (1975) in a similar native grassland community in Hawaii Volcanoes National Park on the island of Hawai'i.

In order to maintain the dominance of native plant species in this habitat, the pigs and goats need to be totally removed from this area as soon as possible. The most feasible means to accomplish this now is to construct a pig-proof fence along the lower boundary of the grassland, augmented by periodic hunting of animals which manage to get back into this area.

The longer this control measure is put off, the better established these and perhaps even more aggressive introduced species will become. As this is the only relatively intact native subalpine grassland remaining in Hawai'i, the urgency in this respect is further underscored.

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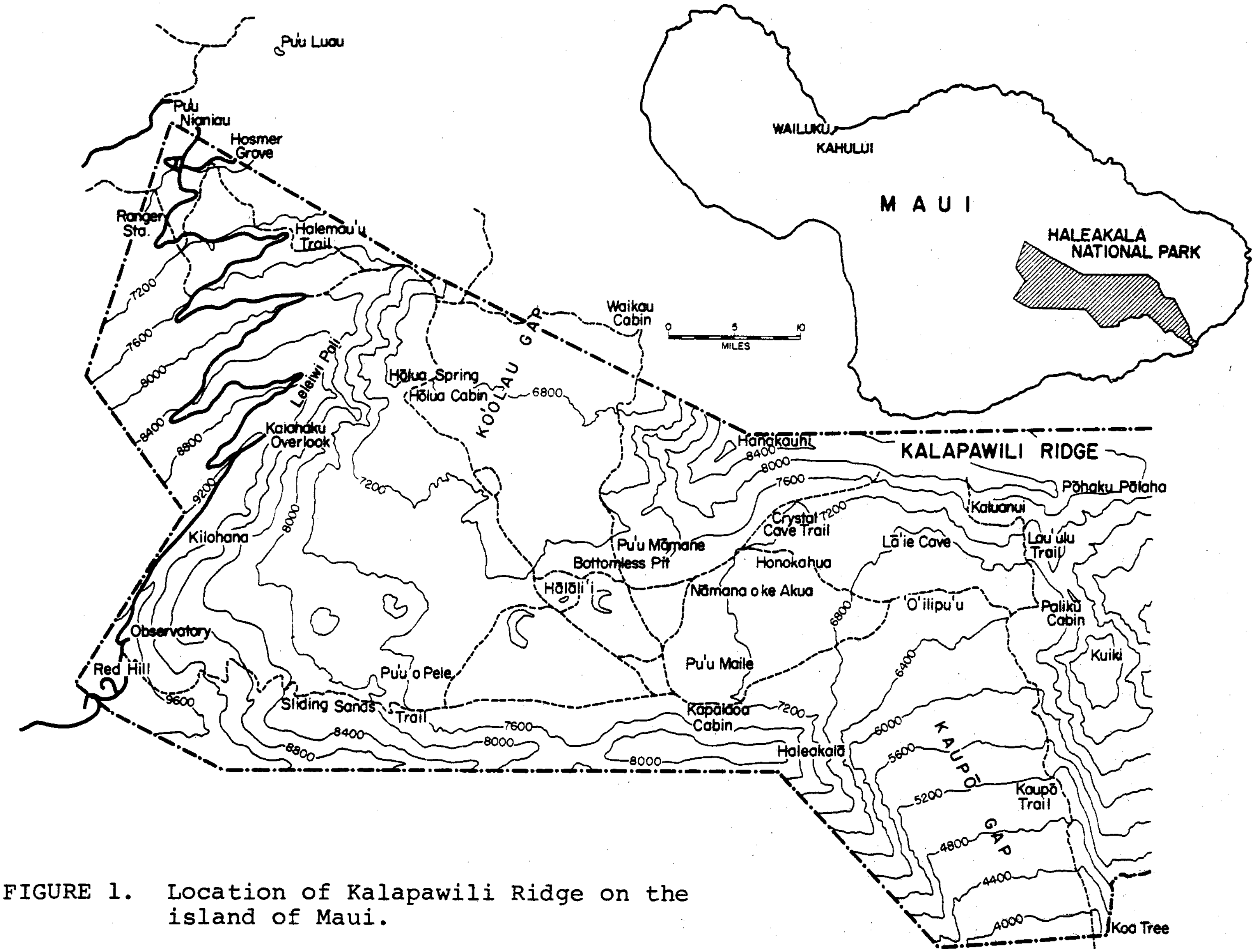

FIGURE 1. Location of Kalapawili Ridge on the island of Maui.

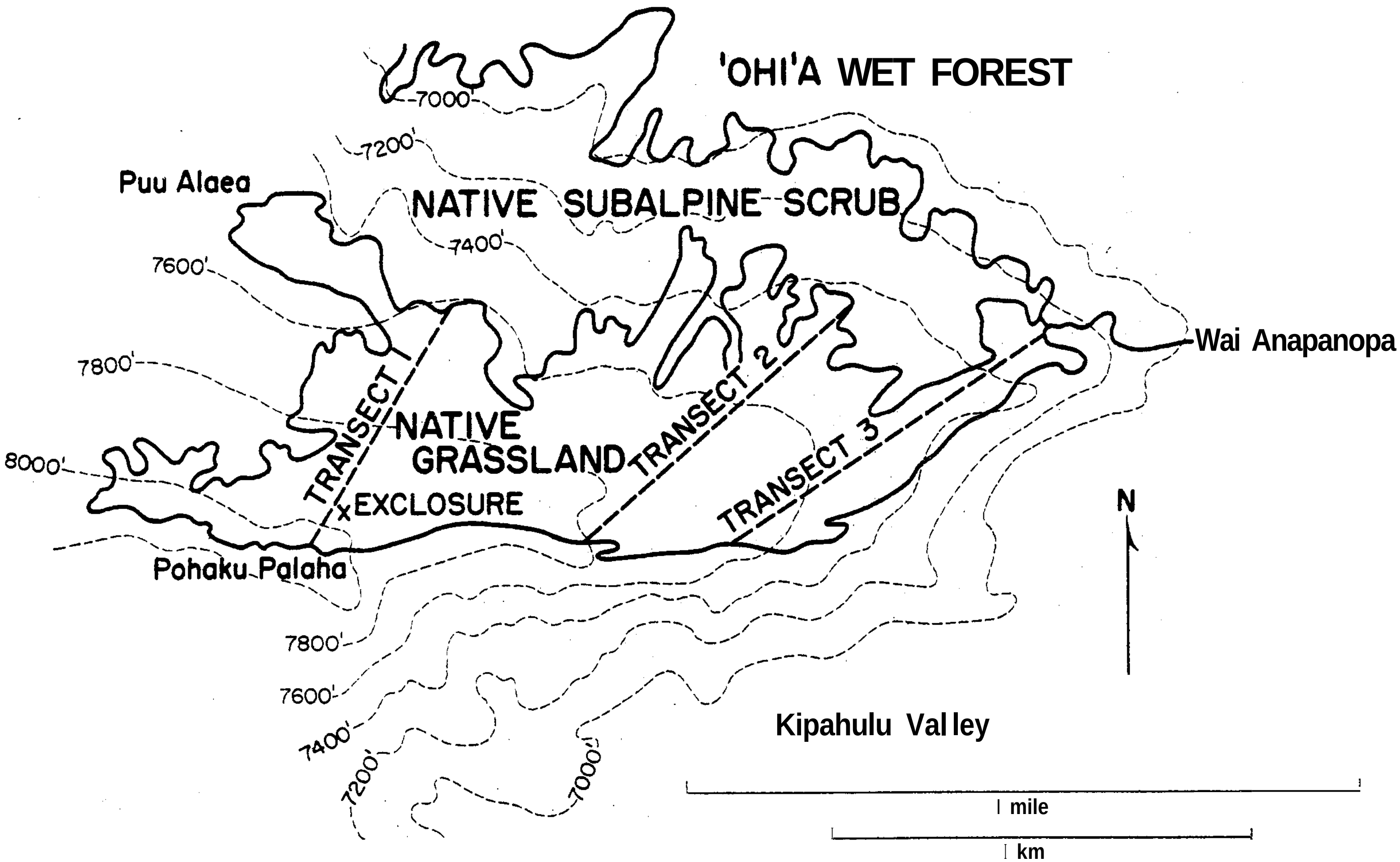

FIGURE 2. Map showing the different vegetation types found on Kalapawili Ridge and the location of the three long transects and fenced exclosure in the native grassland.

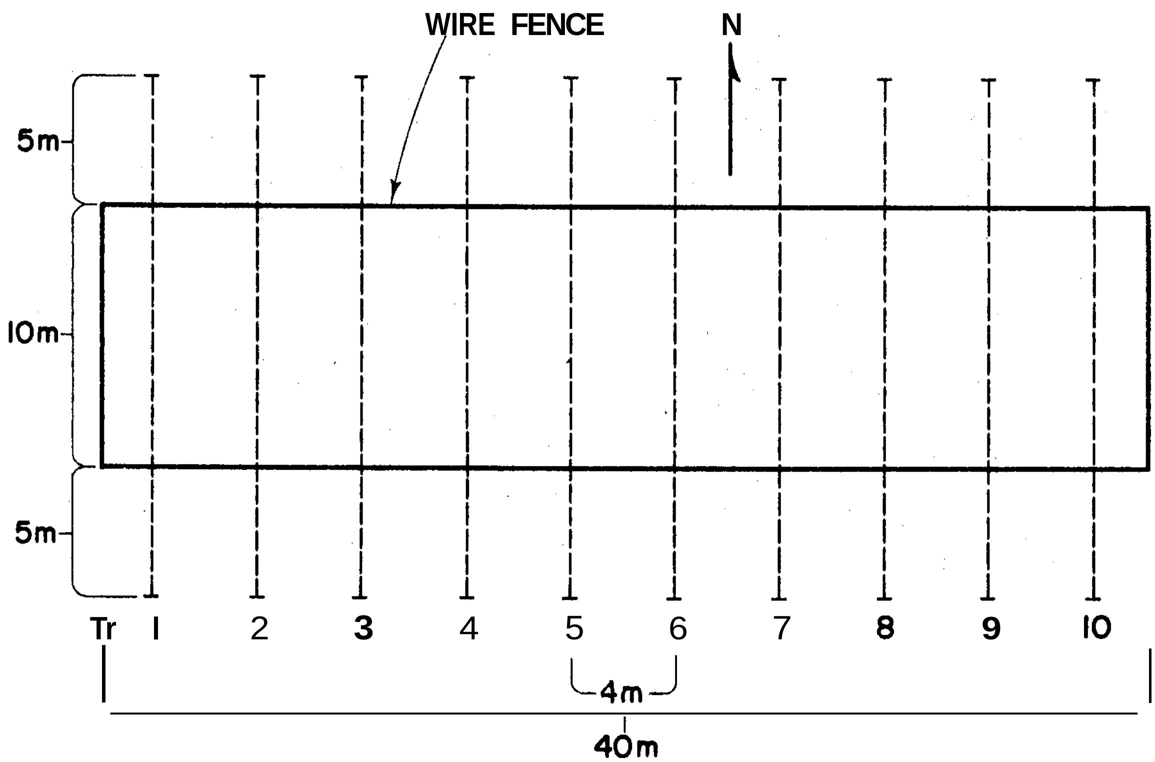

FIGURE 3. Lay-out of the fence and the transects for the Kalapawili Ridge exclosure.

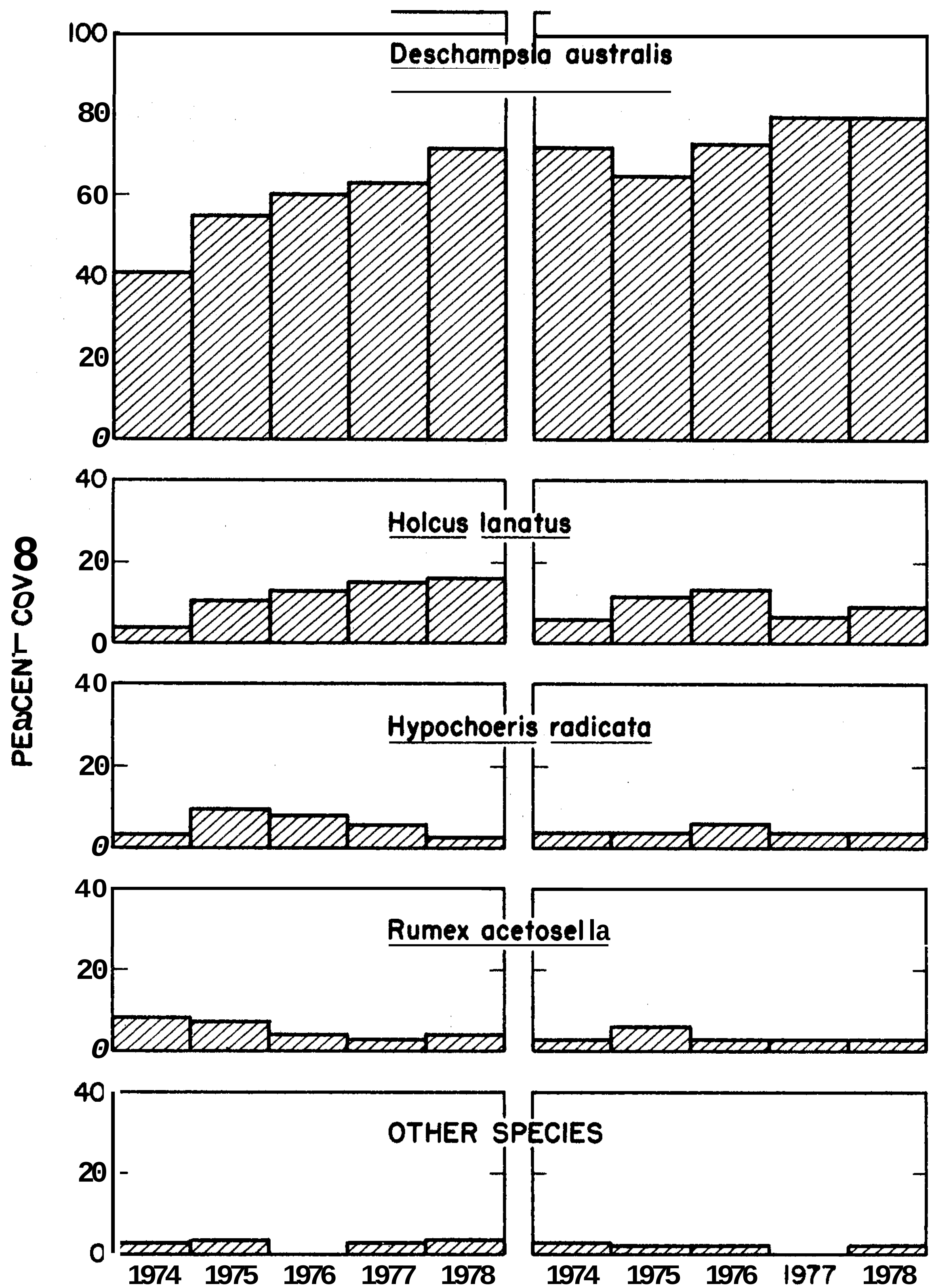

FIGURE 4. Plant species cover for Transects 1 to 5 and 6 to 10 inside the Kalapawili Ridge exclosure for the years 1974 to 1978.

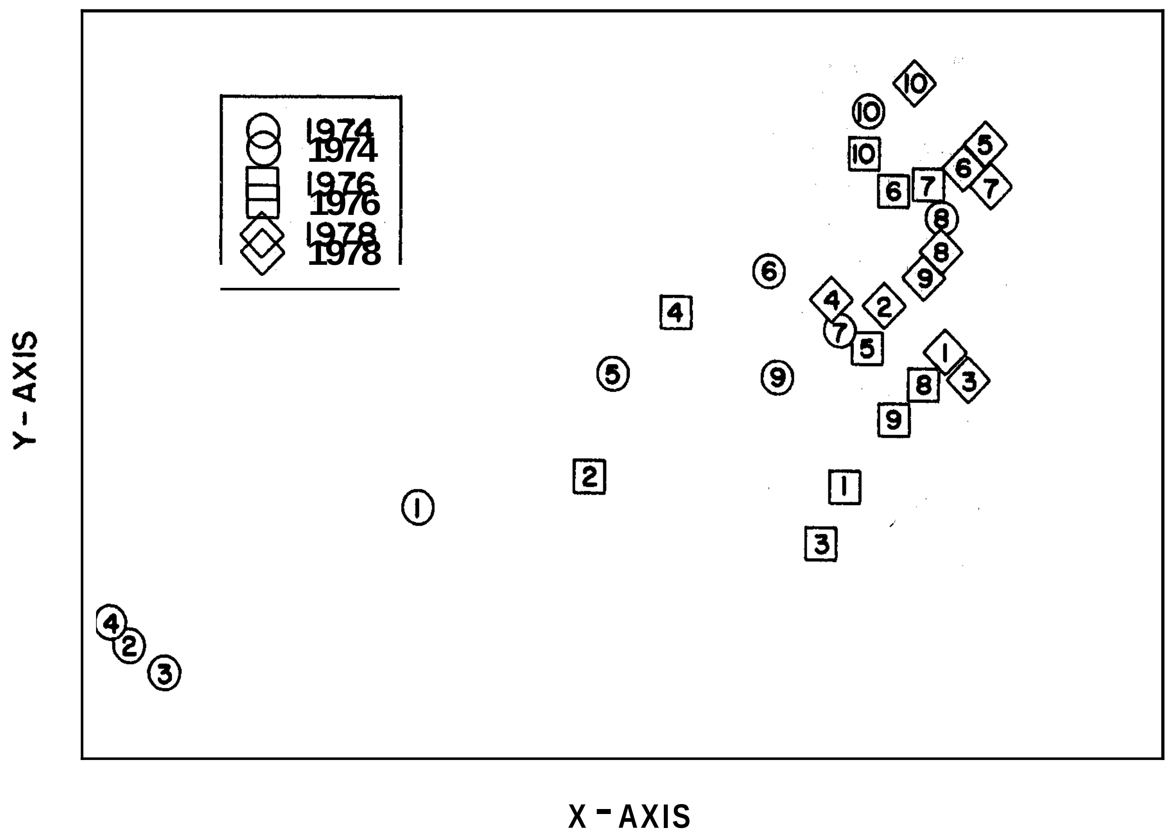

FIGURE 5. Bray and Curtis ordination plot of Transects 1 to 10 inside the exclosure for the years **1974** (○), **1976** (□), and **1978** (◇).

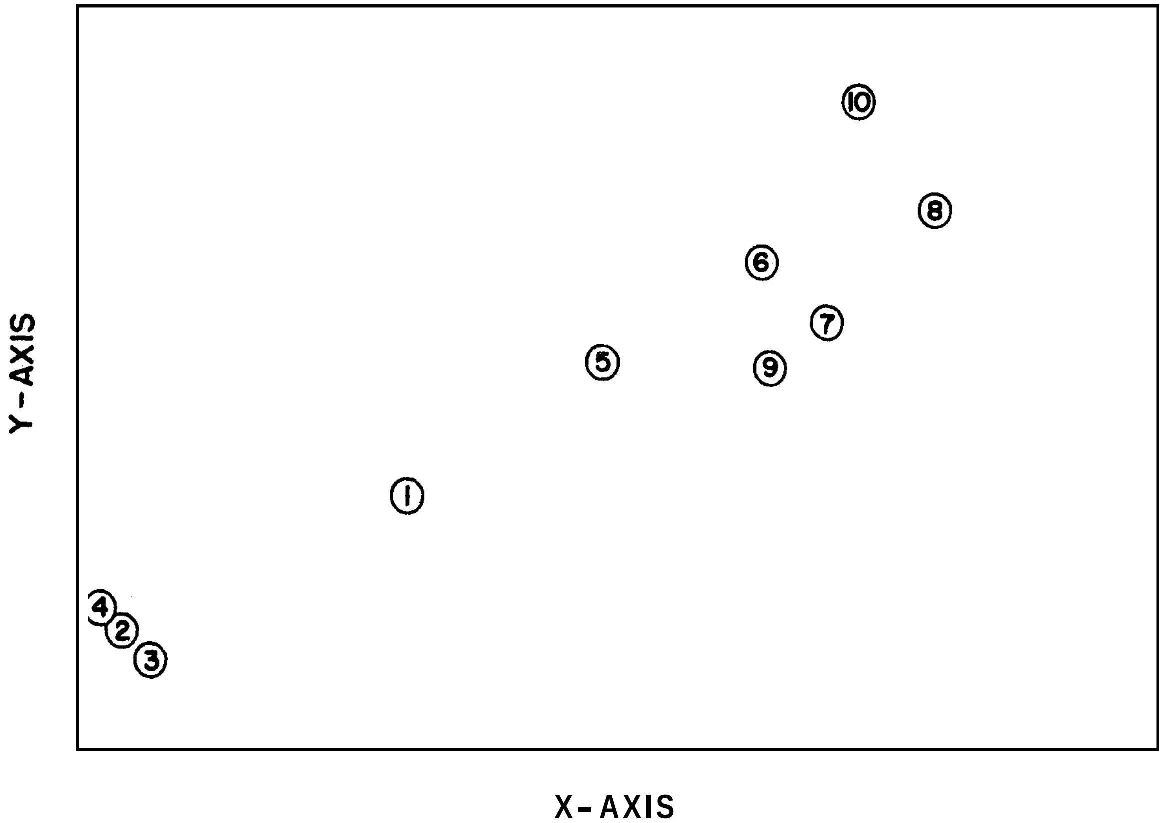

FIGURE 6. Bray and Curtis ordination plot of Transects 1 to 10 inside the exclosure for the year 1974.

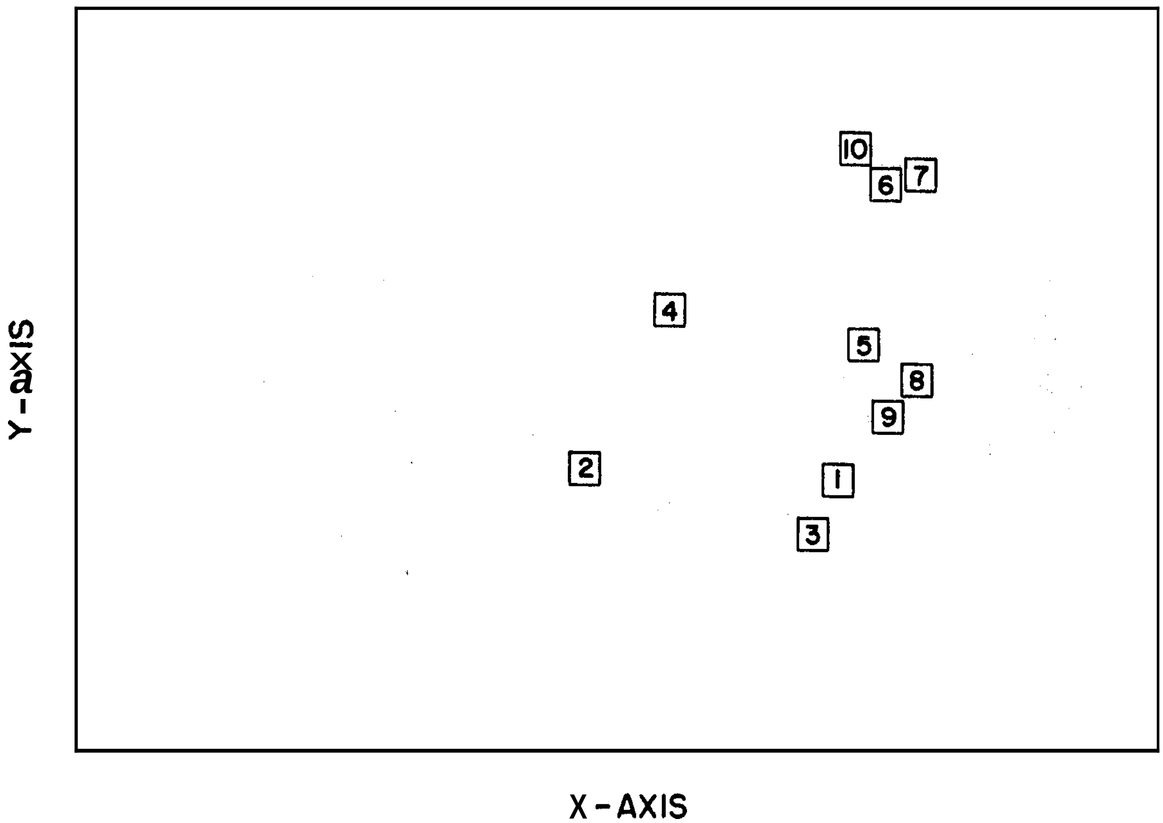

FIGURE 7. Bray and Curtis ordination plot of Transects 1 to 10 inside the exclosure for the year 1976.

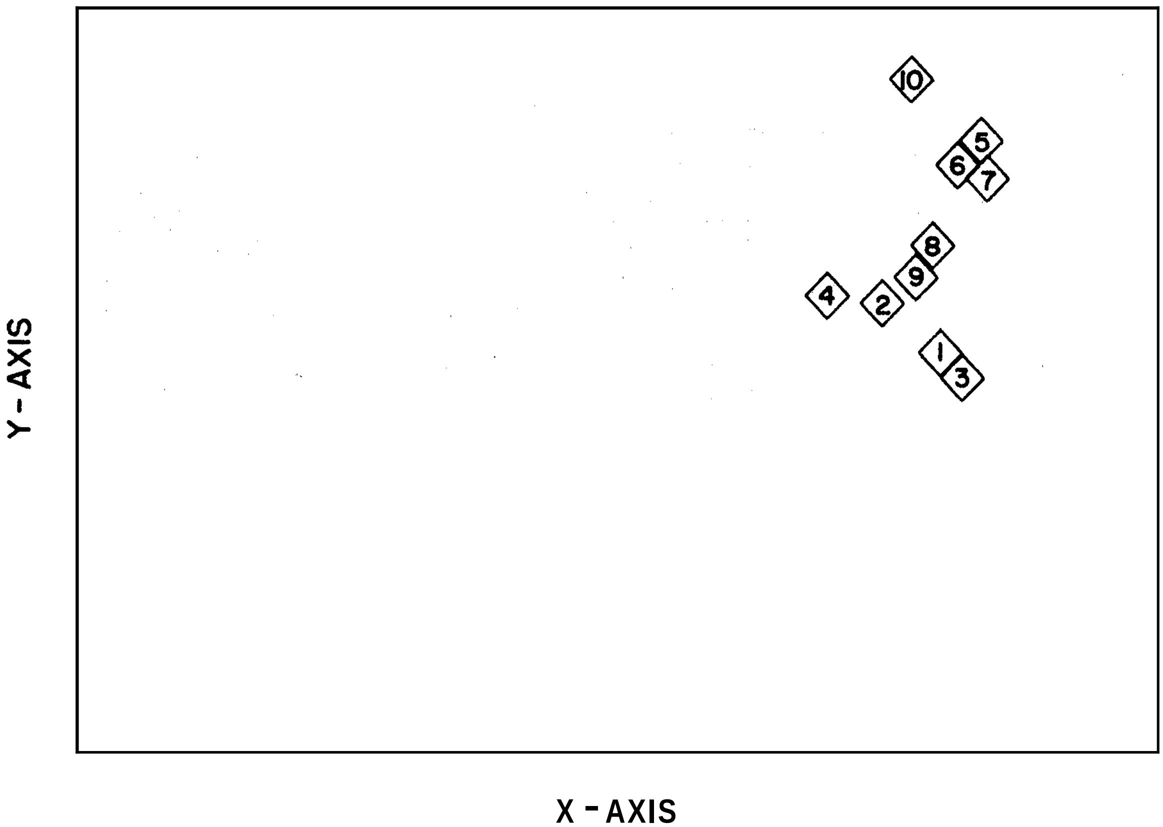

FIGURE 8. Bray and Curtis ordination plot of Transects 1 to 10 inside the exclosure for the year 1978.

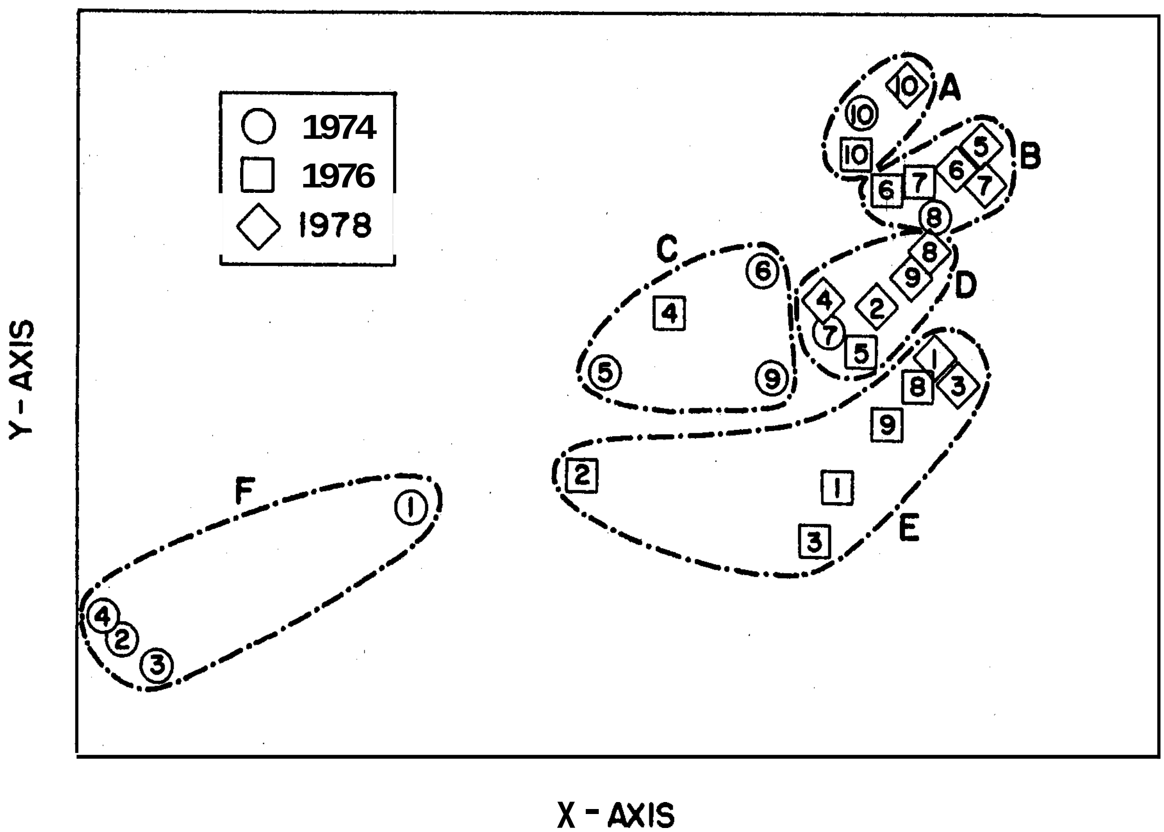

FIGURE 9. Bray and Curtis ordination plot showing Transects 1 to 10 inside the exclosure for the years 1974 (○), 1976 (□), and 1978 (◇), with Plot Groups A–F as described in Table 2.

APPENDIX A

List of plant species found in the Kalapawili Ridge grassland.
(E = Endemic; I = Indigenous; X = Exotic or Introduced)

PTERIDOPHYTA

ASPIDIACEAE: Shield Fern Family

Dryopteris glabra (Brack.) O. Ktze.; (E); Kīlau.
D. paleacea (Sw.) C. Chr.; (E); Laukahi.

BLECHNACEAE: Blechnum Family

Sadleria cyatheoides Kaulf.; (E); 'Ama'uma'u.

DENNSTAEDTIACEAE:

Pteridium aquilinum (L.) Kuhn.
var. *decompositum* (Gaud.) Tryon; (I); Bracken.

MONOCOTYLEDONAE

CYPERACEAE: Sedge Family

Carex alligata F. Boott; (E); Hawaiian sedge.
C. macloviana D'Urv.; (I); St. Malo's sedge.
Uncinia sp.; (E).

GRAMINEAE: Grass Family

Deschampsia australis Nees ex Steud.; (E).
Holcus lanatus L.; (X); Velvetgrass.
Sacciolepis indica (L.) Chase; (X); Glenwoodgrass.

JUNCACEAE: Rush Family

Juncus bufonius L.; (X); Common toad rush.
Luzula hawaiiensis Buch.; (E).

DICOTYLEDONAE

COMPOSITAE: Sunflower Family

Argyroxiphium sandwicense DC.; (E); 'Āhinahina.
Hypochaeris radicata L.; (X); Gosmore.

EPACRIDACEAE: Epacris Family

Styphelia tameiameiae (Cham.) F. Muell.; (E); Pūkiawe.

ERICACEAE: Heath Family

Vaccinium berberifolium (Gray) Skottsb.; (E); 'Ōhelo.
V. reticulatum Sm.; (E); 'Ōhelo.

POLYGONACEAE: Buckwheat Family

Rumex acetosella L.; (X); Sheep sorrel.

ROSACEAE: Rose Family

Fragaria chiloensis (L.) Duch.
var. sandwicensis Deg. & Deg.; (E); 'Ōhelo-papa.
Rubus hawaiiensis Gray; (E); 'Ākala.
R. penetrans Bailey; (X); Prickly Florida blackberry.

RUBIACEAE: Coffee Family

Coprosma ernodeoides Gray; (E); Kūkae-nēnē.